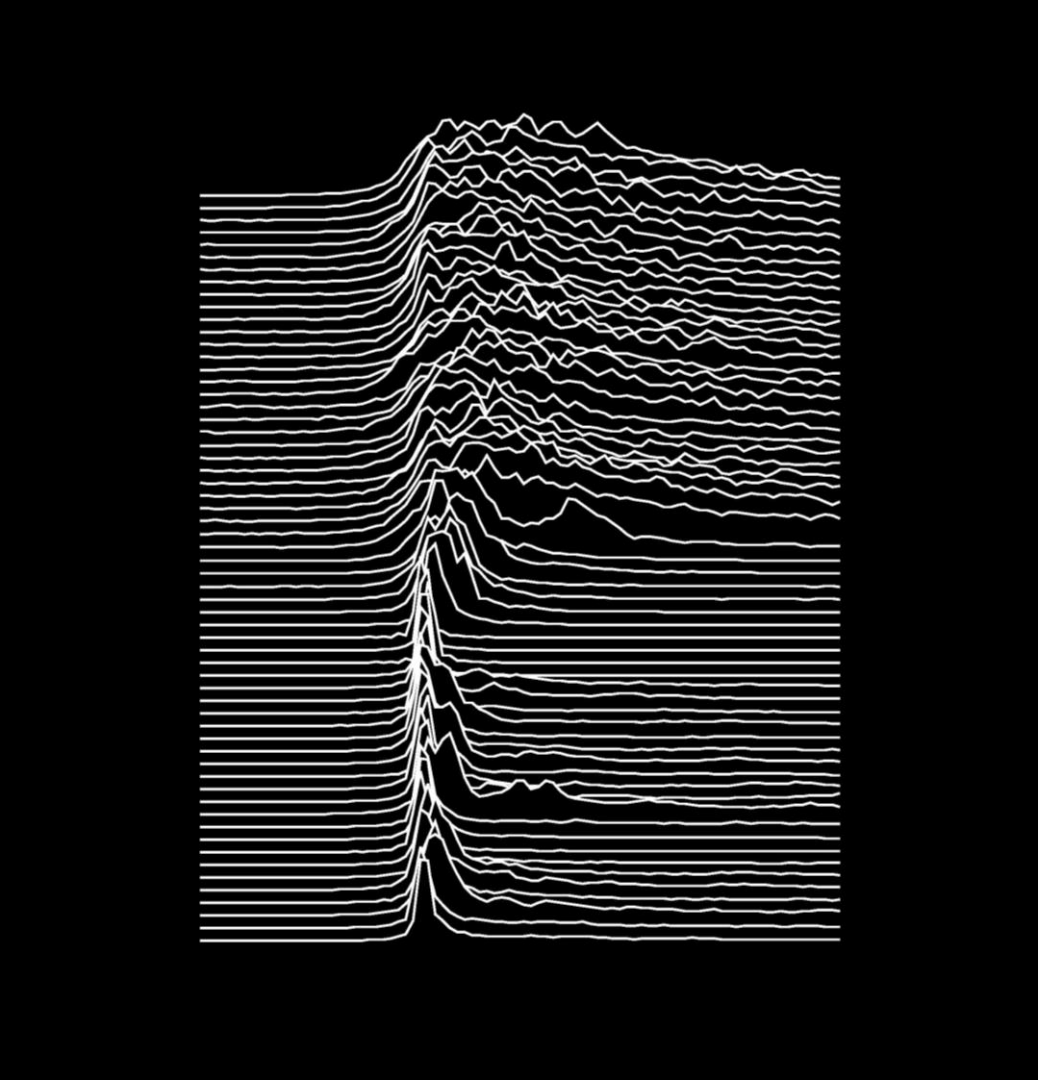

New techniques for radar altimetry of sea ice and the polar oceans

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Laboratory for Satellite Altimetry
NOAA·NESDIS·STAR

Summary

Radar altimetry is a *proven tool* for studying and monitoring the polar oceans (ice freeboard/thickness/volume & SSH)

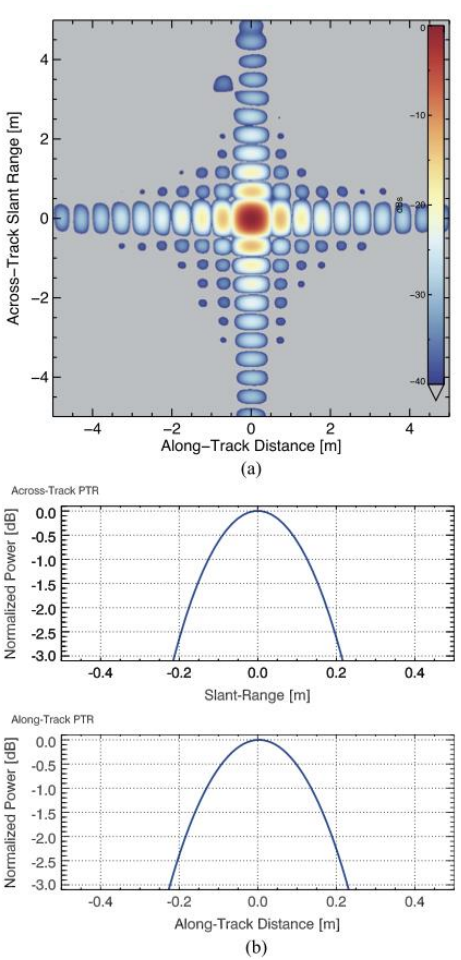
But, here I will discuss...

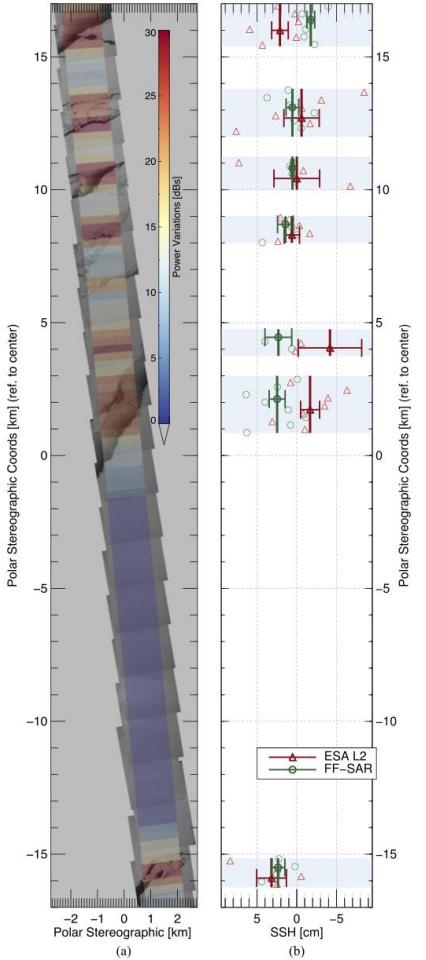
1. Investigating improving sea ice retrievals from SAR altimeters with ‘fully-focused’ processing
2. The SWOT mission, that offers to provide swath elevation measurements of ice freeboard/thickness and SSH

Fully-focused SAR altimetry

FFSAR: Introduction

- Accounts for the phase-evolution of scatterers
- Perform inter-burst coherent integration, potentially during the entire illumination time of a surface scatterer
- Can achieve along-track resolution of ~50cm



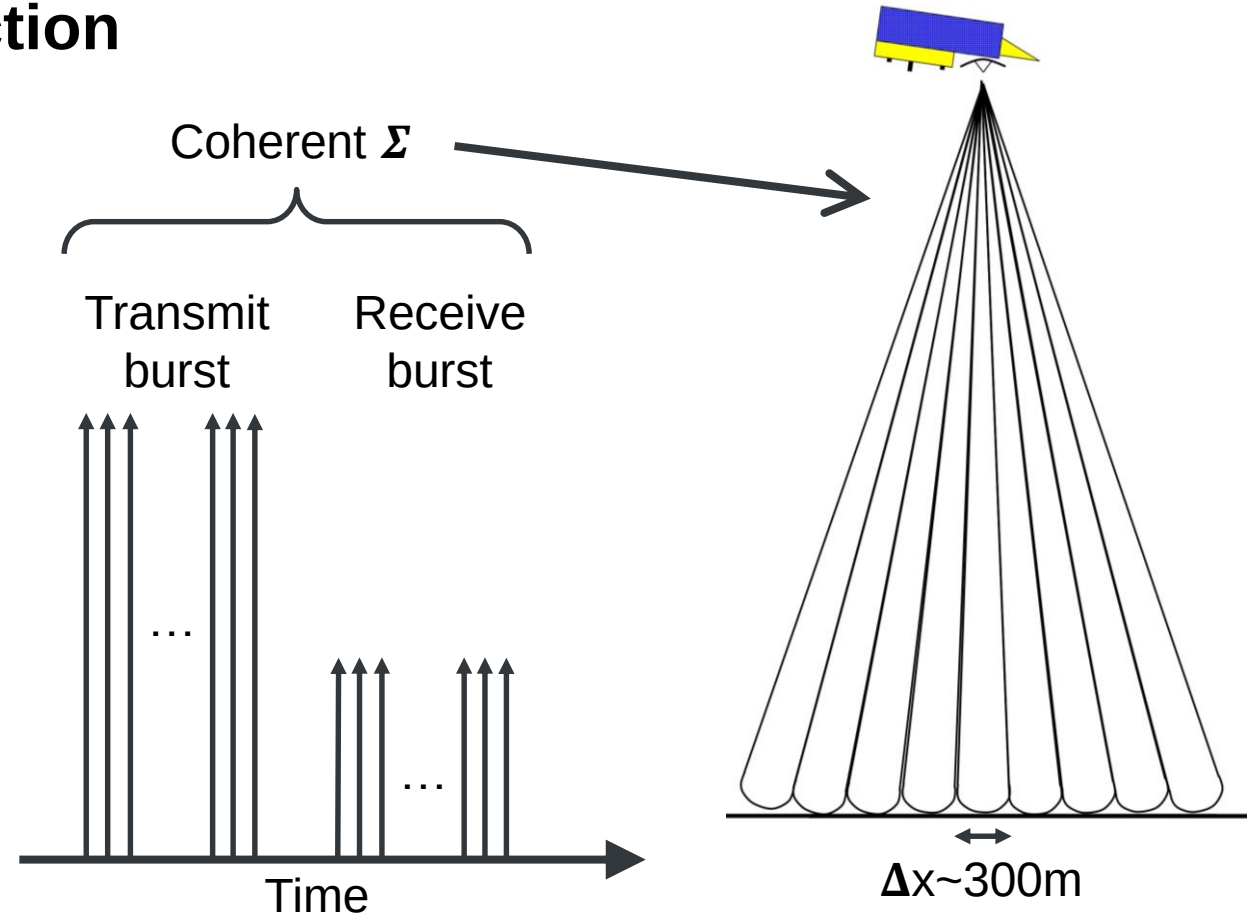


Figures: Egido & Smith (2017), “Fully Focused SAR Altimetry: Theory and Applications”, *IEEE TGRS*, 55

FFSAR: Introduction

Delay/Doppler

Coherent processing over individual bursts

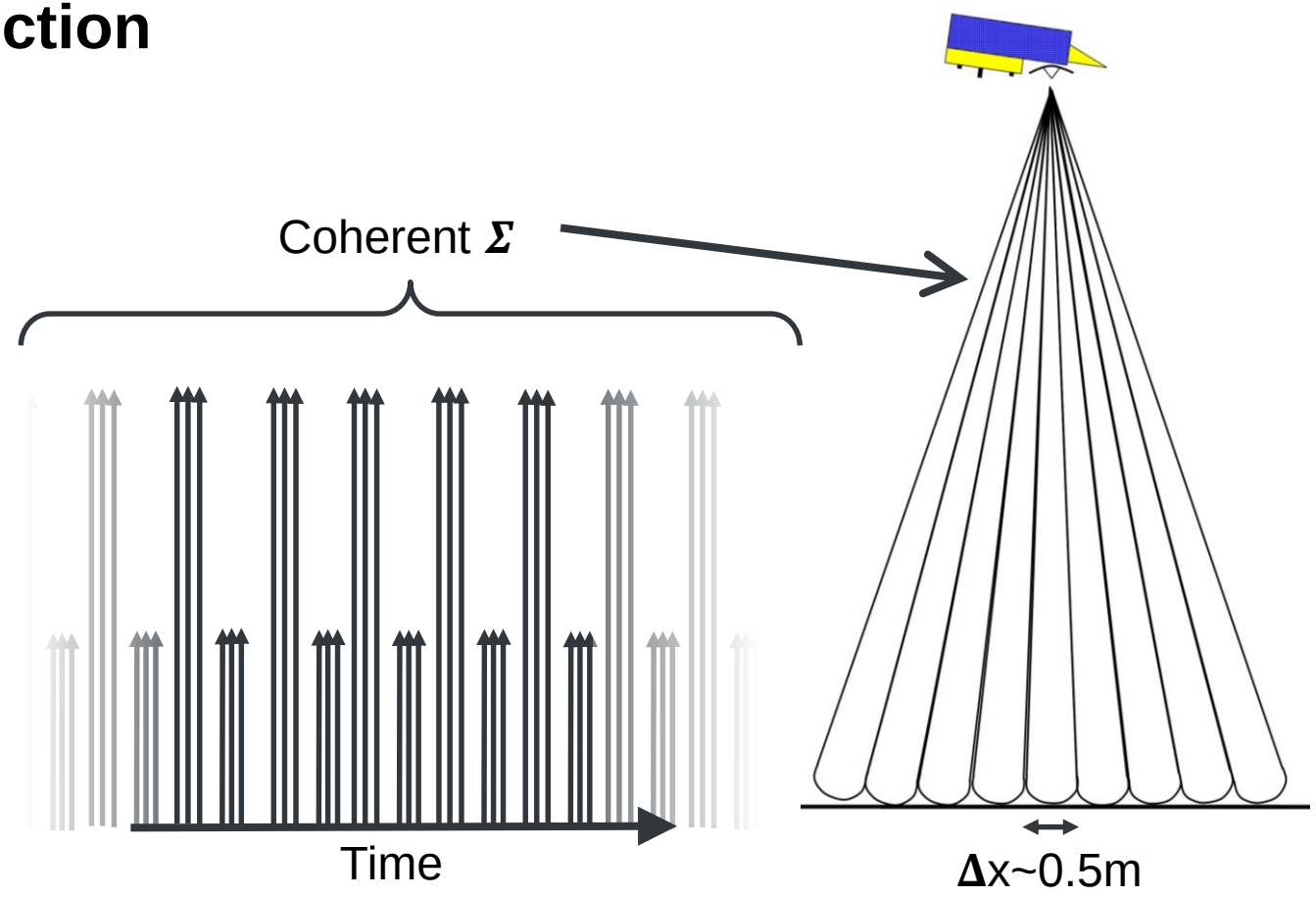


FFSAR: Introduction

Fully-focused

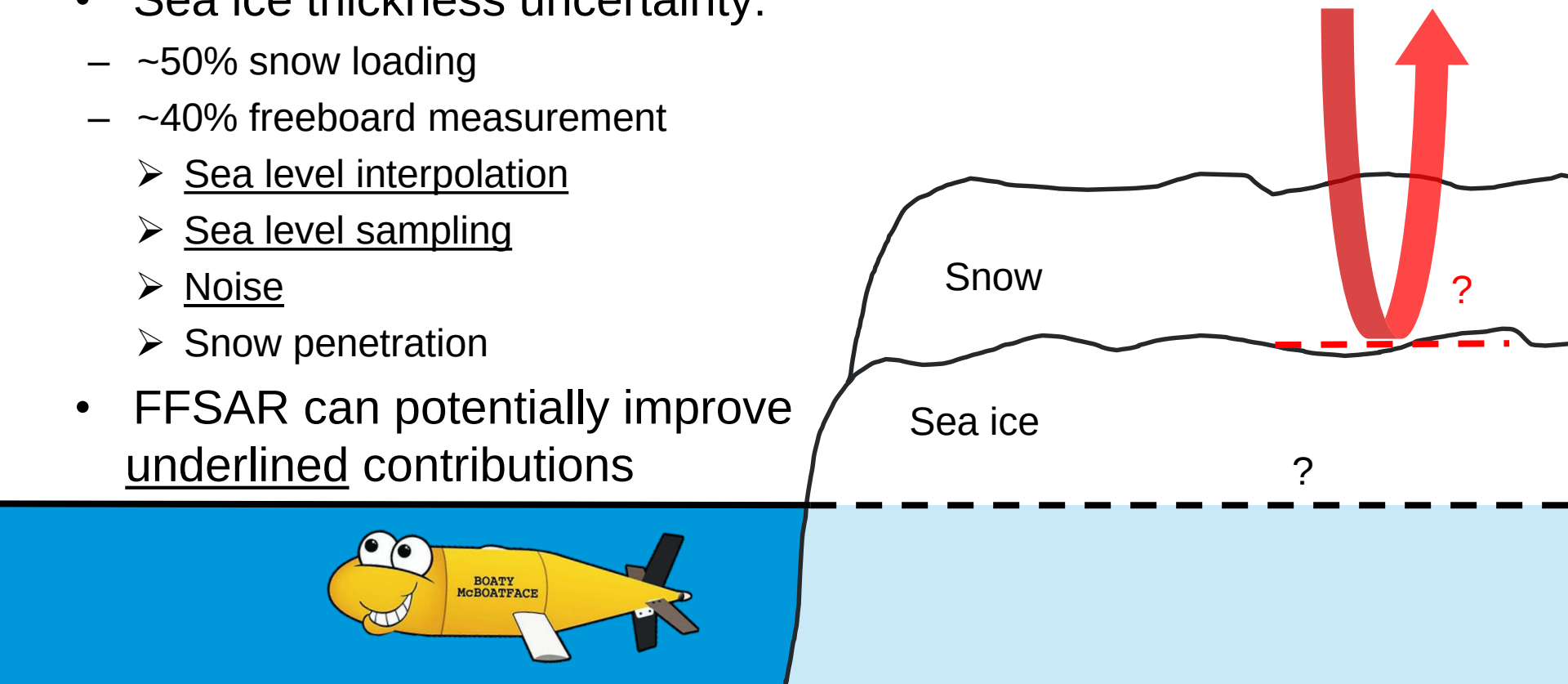
Coherent processing over many bursts

Get more effective looks at the surface



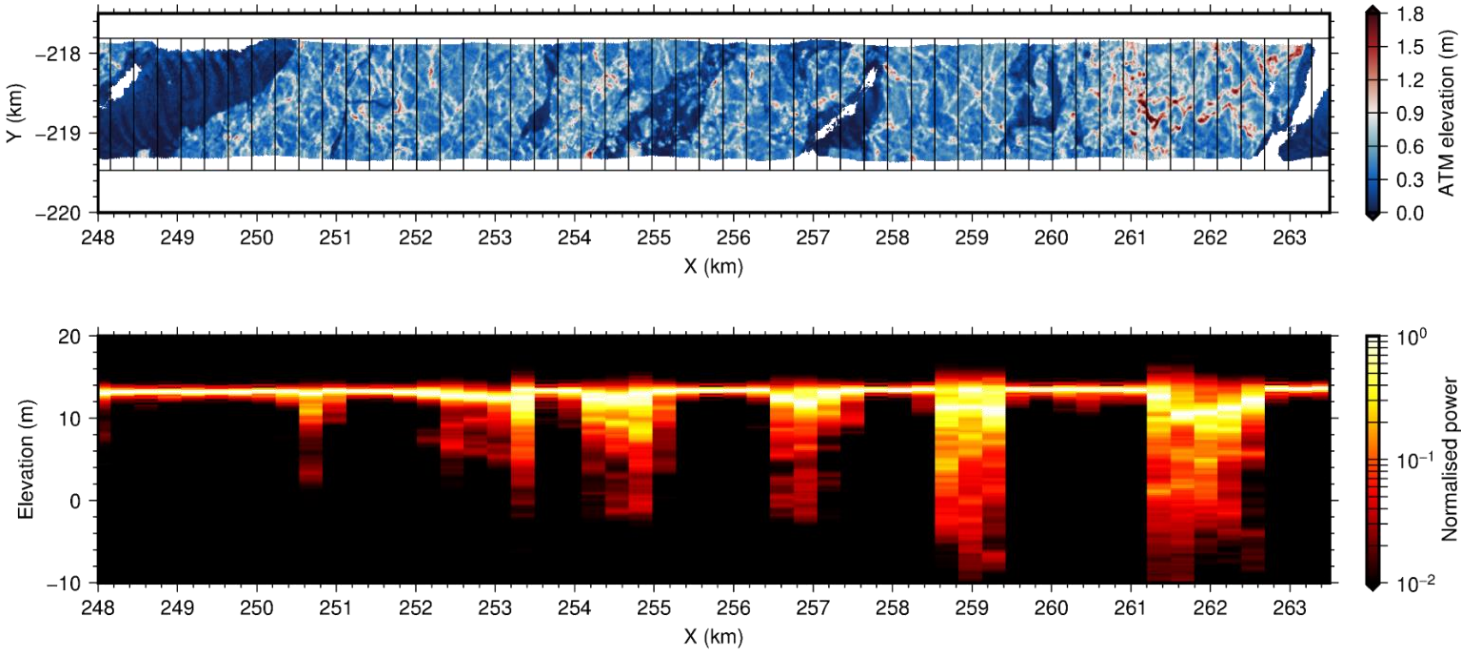
FFSAR: Why is it interesting for sea ice?

- Sea ice thickness uncertainty:
  - ~50% snow loading
  - ~40% freeboard measurement
    - Sea level interpolation
    - Sea level sampling
    - Noise
    - Snow penetration
- FFSAR can potentially improve underlined contributions



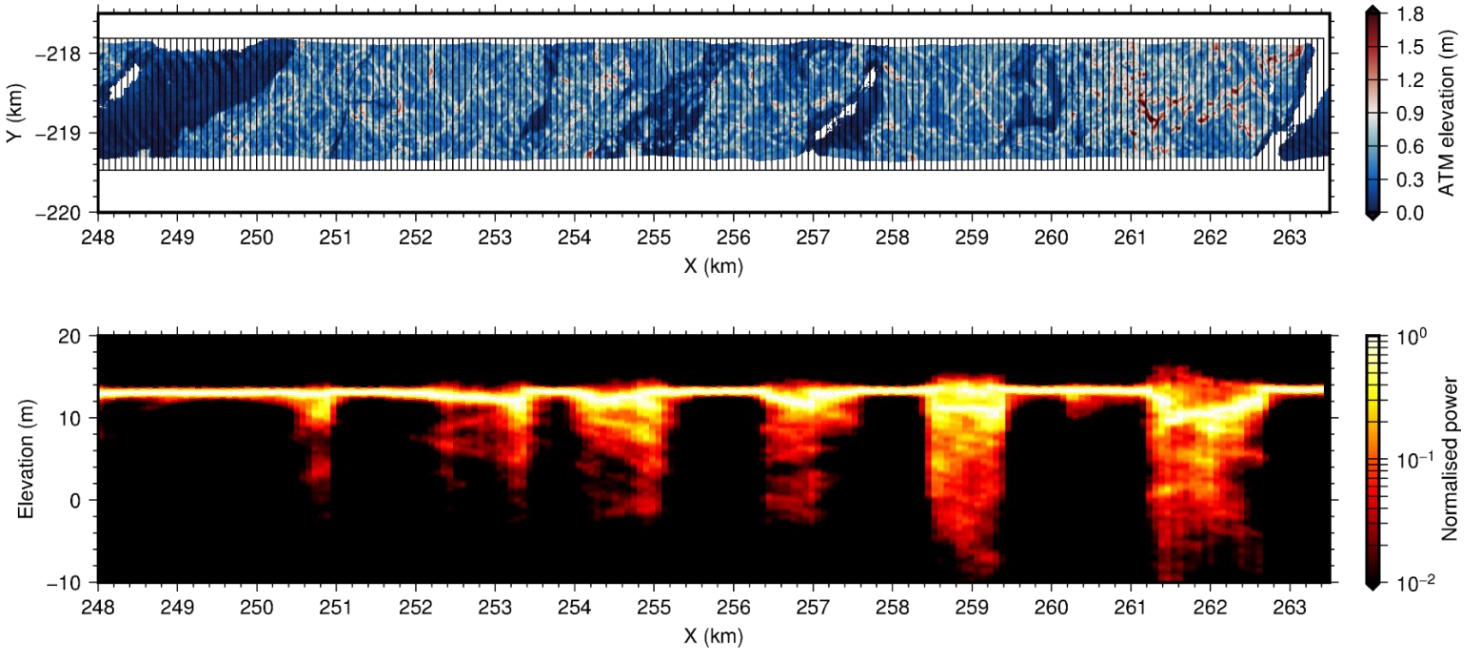
FFSAR: Improved along-track sampling

20Hz ESA Level-1b delay/Doppler



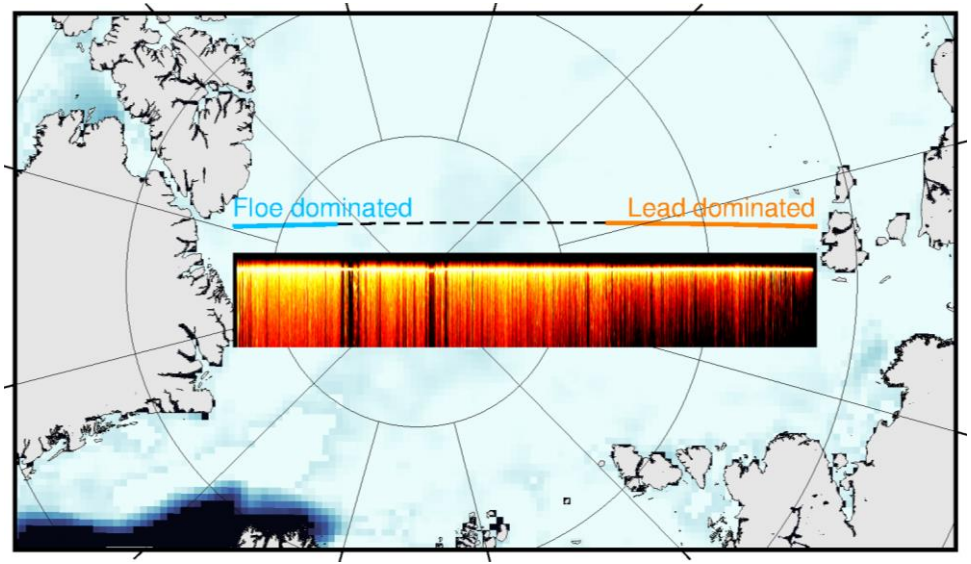
FFSAR: Improved along-track sampling

80Hz multi-looked FFSAR



FFSAR: Along-track analysis

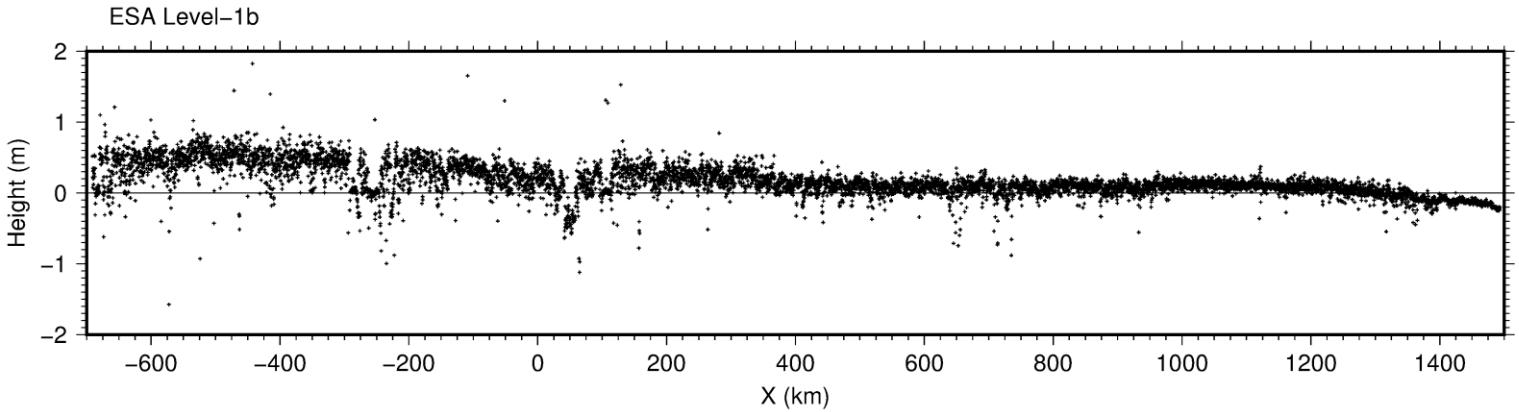
26 March 2014



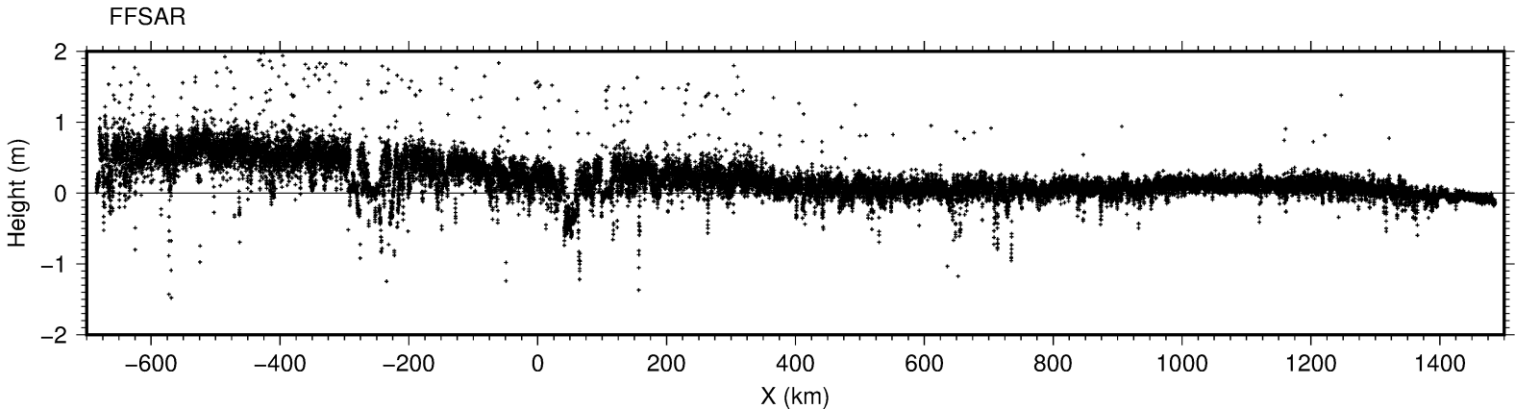
- Perform along-track comparison between ESA level-1b delay/Doppler data and FFSAR equivalent

FFSAR: Along-track analysis

ESA Level-1b

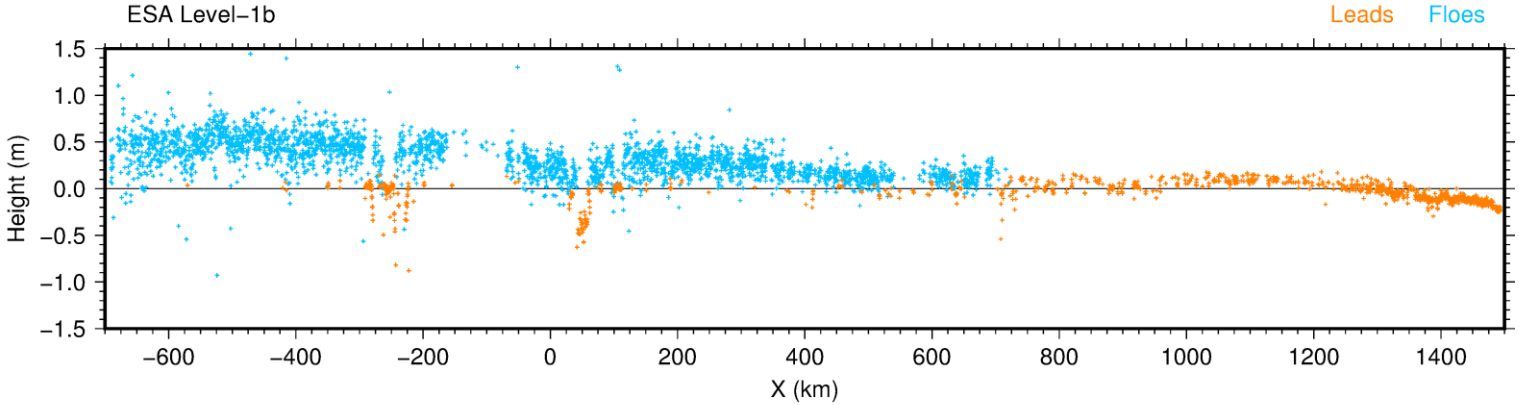


80Hz FFSAR

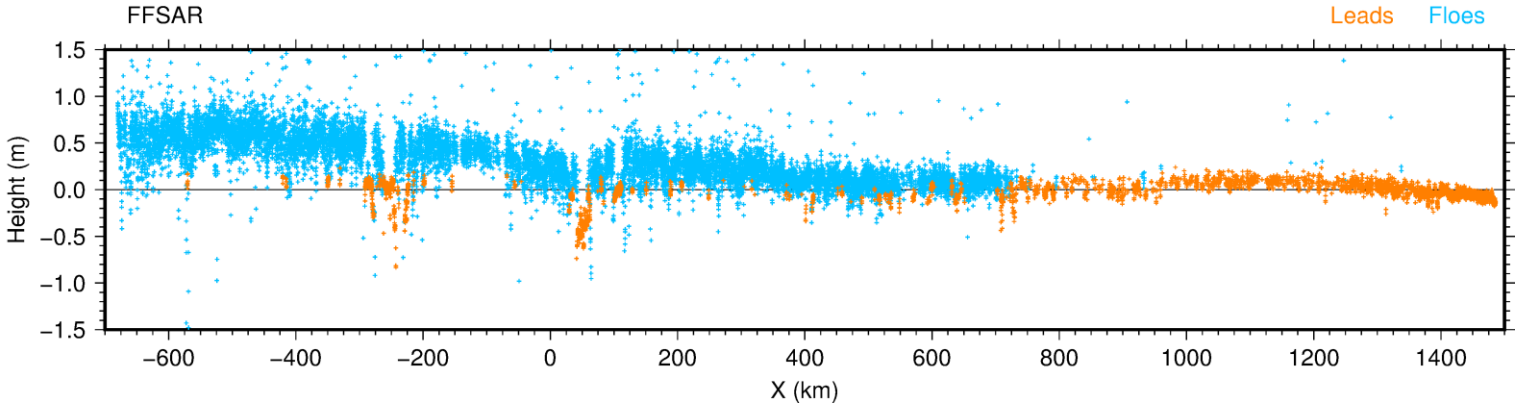


FFSAR: Along-track analysis

ESA Level-1b



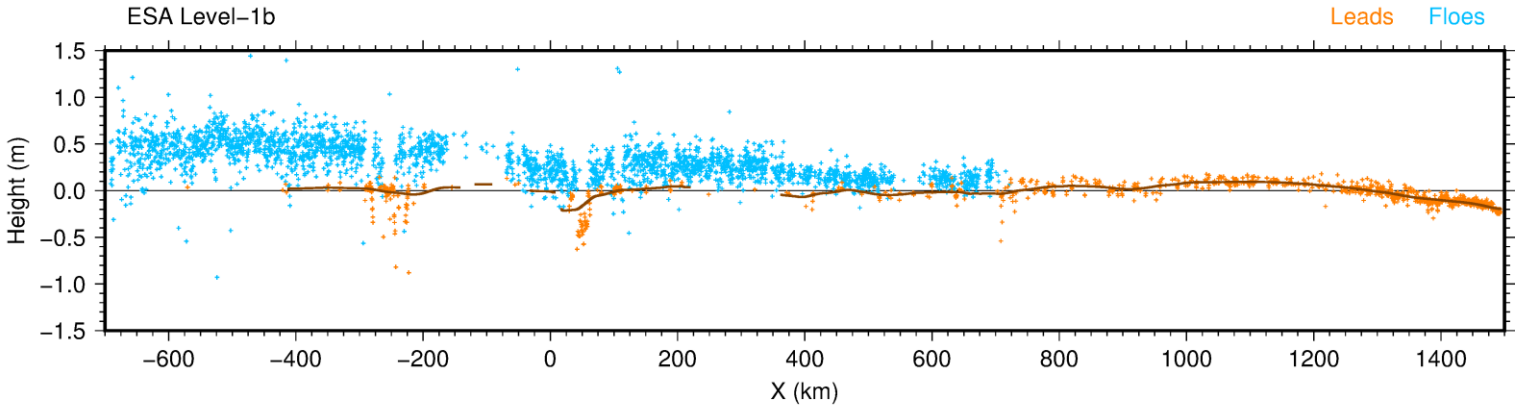
80Hz FFSAR



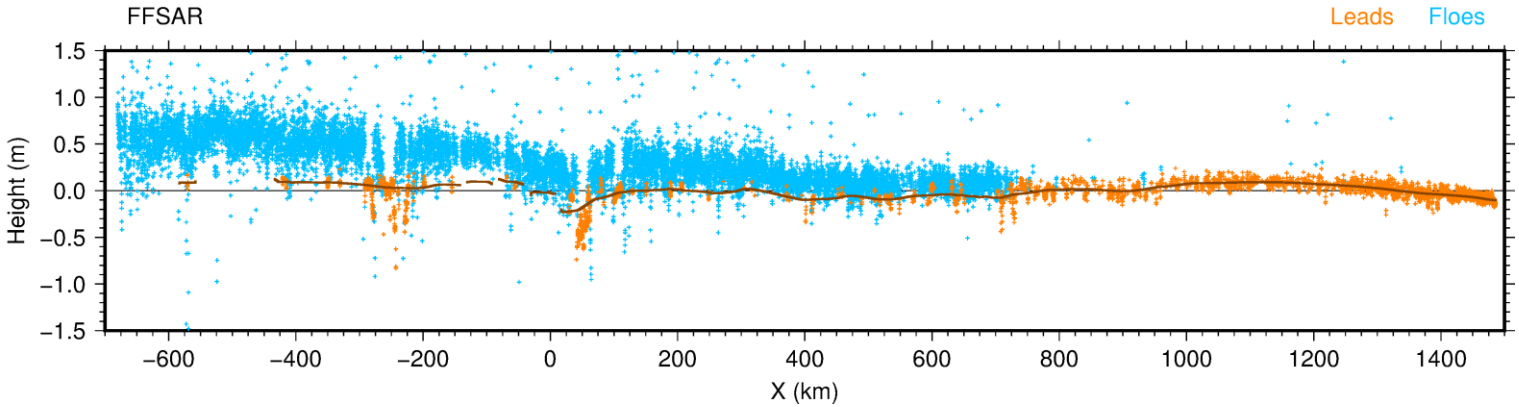
FFSAR: Along-track analysis

ESA Level-1b

Floes
Leads



80Hz FFSAR

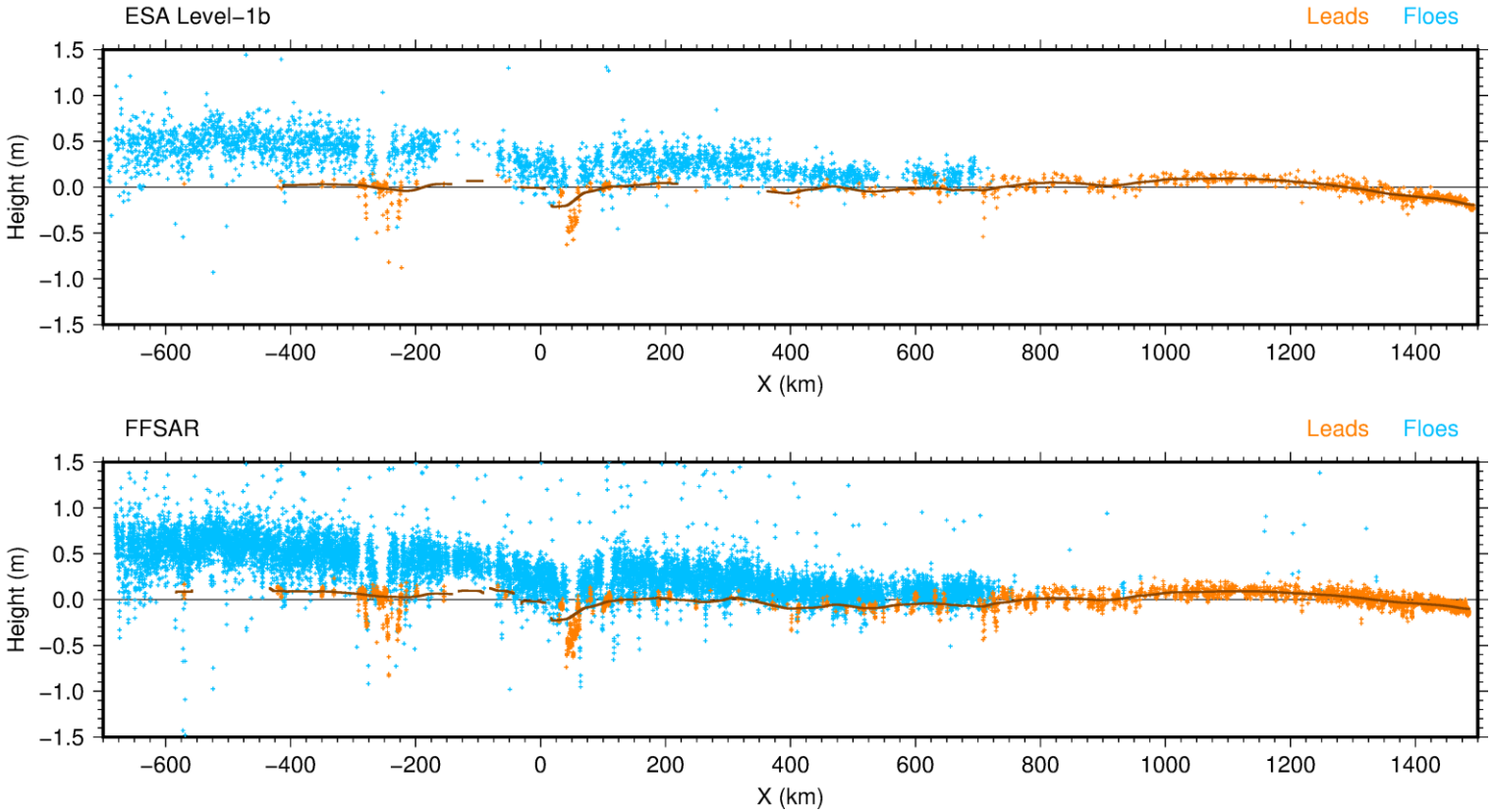


FFSAR: Along-track analysis

ESA Level-1b

Floes
Leads

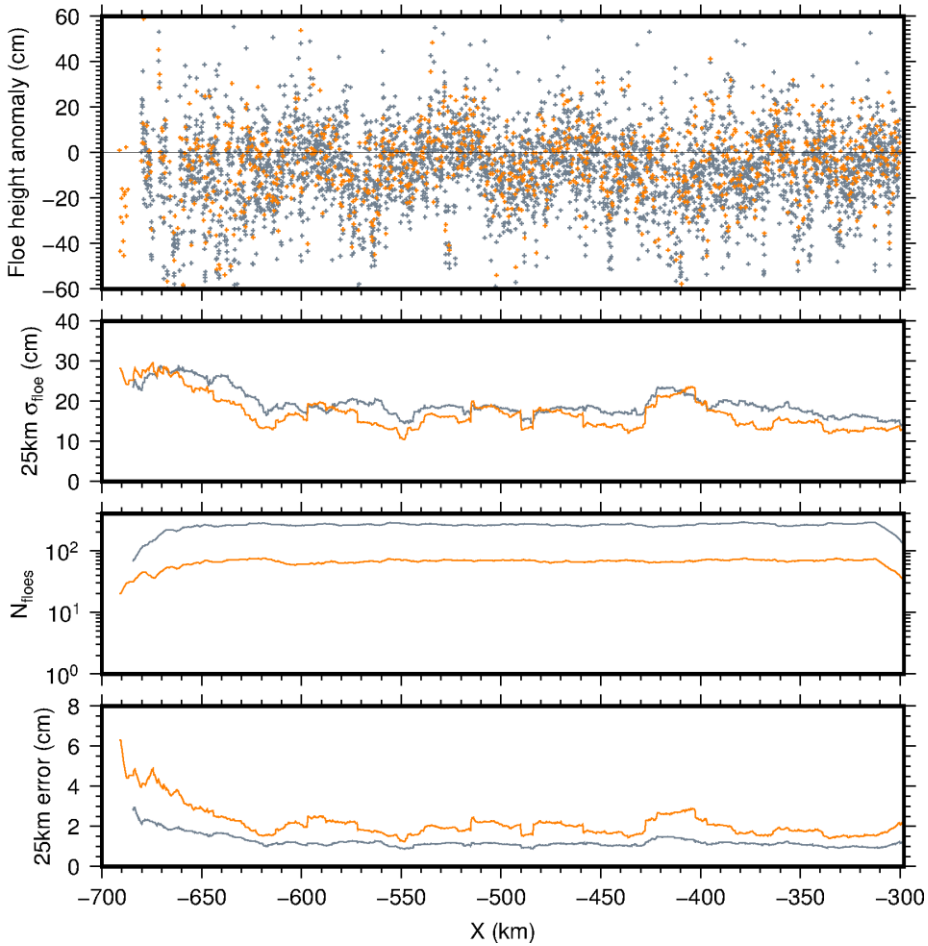
80Hz FFSAR



FFSAR: Along-track analysis

Floe height anomalies

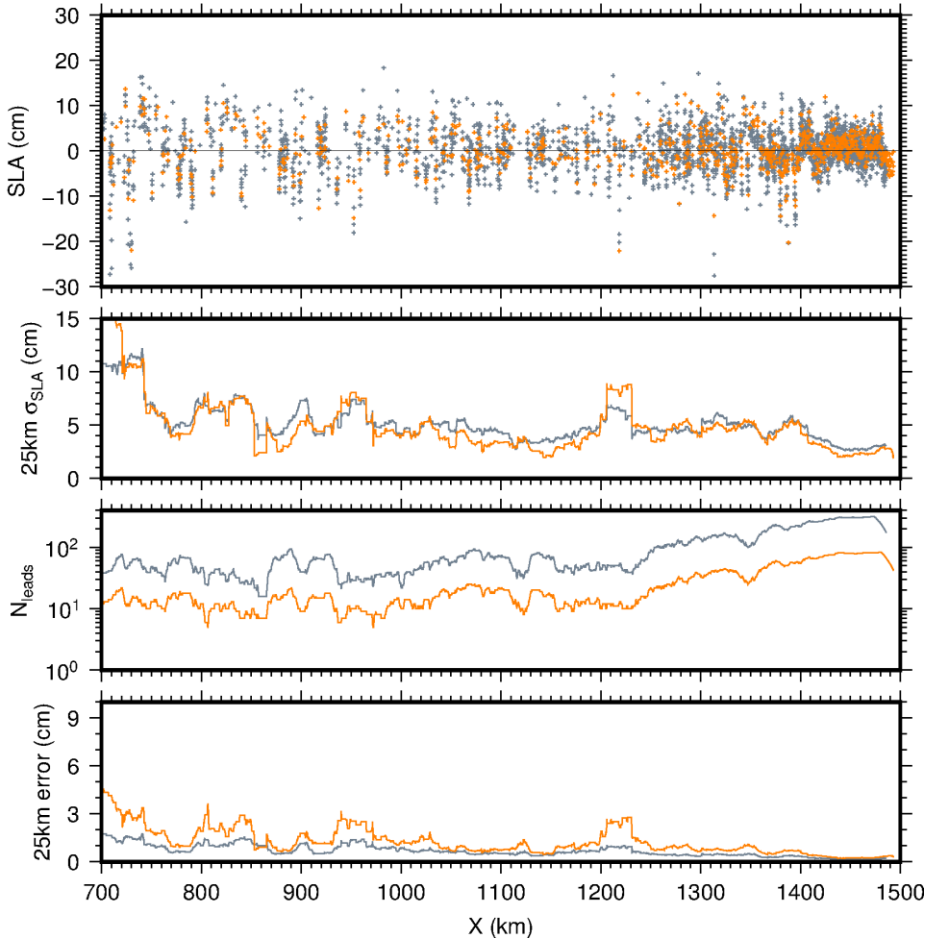
- ESA Level-1b
- 80Hz FFSAR
- 25km along-track statistics
  - Similar along-track standard deviation
  - More floes detected
  - Improvements in noise (√N)



FFSAR: Along-track analysis

Sea level anomalies

- ESA Level-1b
- 80Hz FFSAR
- 25km along-track statistics
  - Similar along-track standard deviation
  - More floes detected
  - Improvements in noise (√N)



FFSAR: Implications for potential CryoSat-FO

- Interleaved operation is better than ‘burst’ operation, especially for FFSAR processing
  - But more power+data* hungry (*power+data=money)
- Studies for CryoSat follow-on:
  - Inter-leaved vs. burst operation
  - FFSAR ground segment
  - FFSAR for ice sheets/SARIn

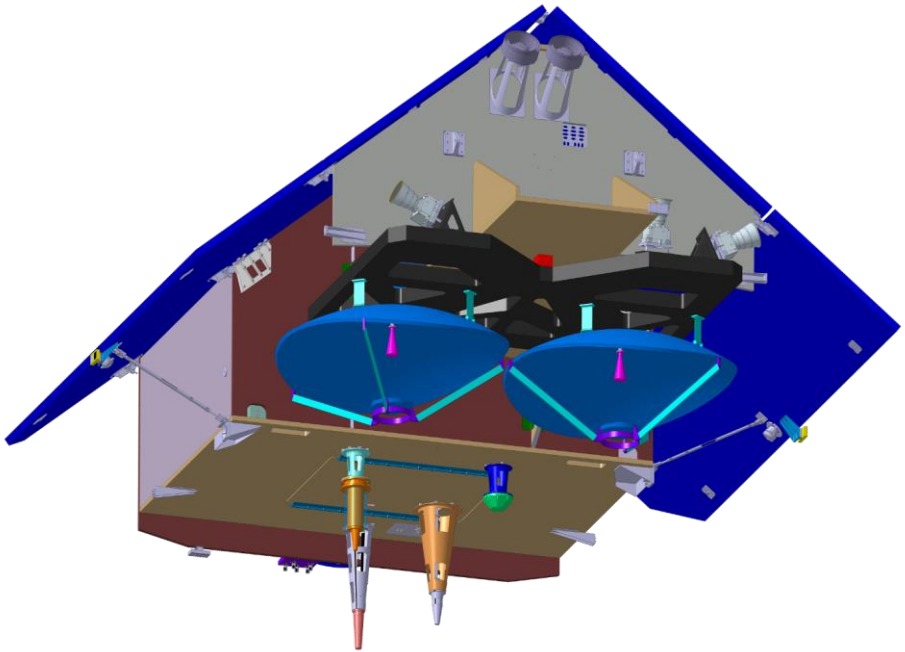


Image courtesy: Robert Cullen

Surface Water Ocean Topography mission sea ice retrievals

SWOT: Background

- Launch: 2021
- Inclination: 78º
- 21-day repeat
- Mission:
  - Determine ocean (sub-) mesoscale circulation at 15km resolution
  - Measure terrestrial surface water storage and river discharge at sub-monthly to annual time scales

SWOT: Payload

- Ka-band Radar Interferometer (KaRIn)
  - 35.75GHz central frequency
  - Generates 2 swaths of elevation 10-60km either side of nadir
  - Resolution: 2.5m along-track x 10m (far-swath) to 70m (near-swath) across-track
- Poseidon-class nadir altimeter (Ku- & C-band)

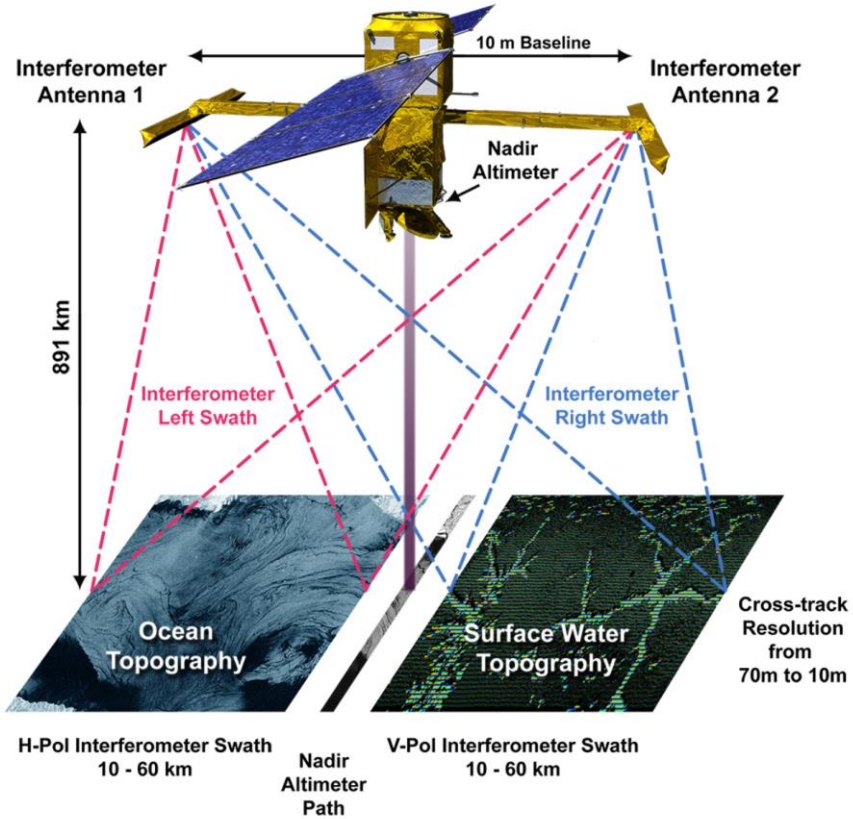
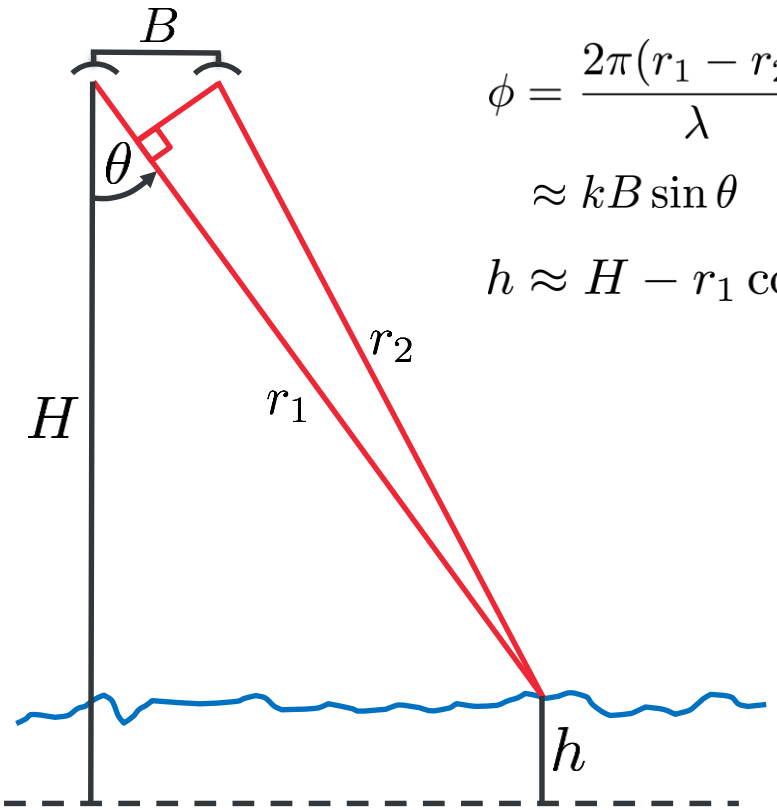


Image: D. Esteban Fernandez, 2013, “SWOT Project Mission Performance and Error Budget”, JPL D-79084

SWOT: Measurement

- Use phase difference of signal received by two antennas to estimate look angle
- Can be used to estimate the surface elevation *h*



$$\phi = \frac{2\pi(r_1 - r_2)}{\lambda}$$

$$\approx kB\sin\theta$$

$$h \approx H - r_1\cos\theta$$

SWOT: Sea ice challenges

Main questions

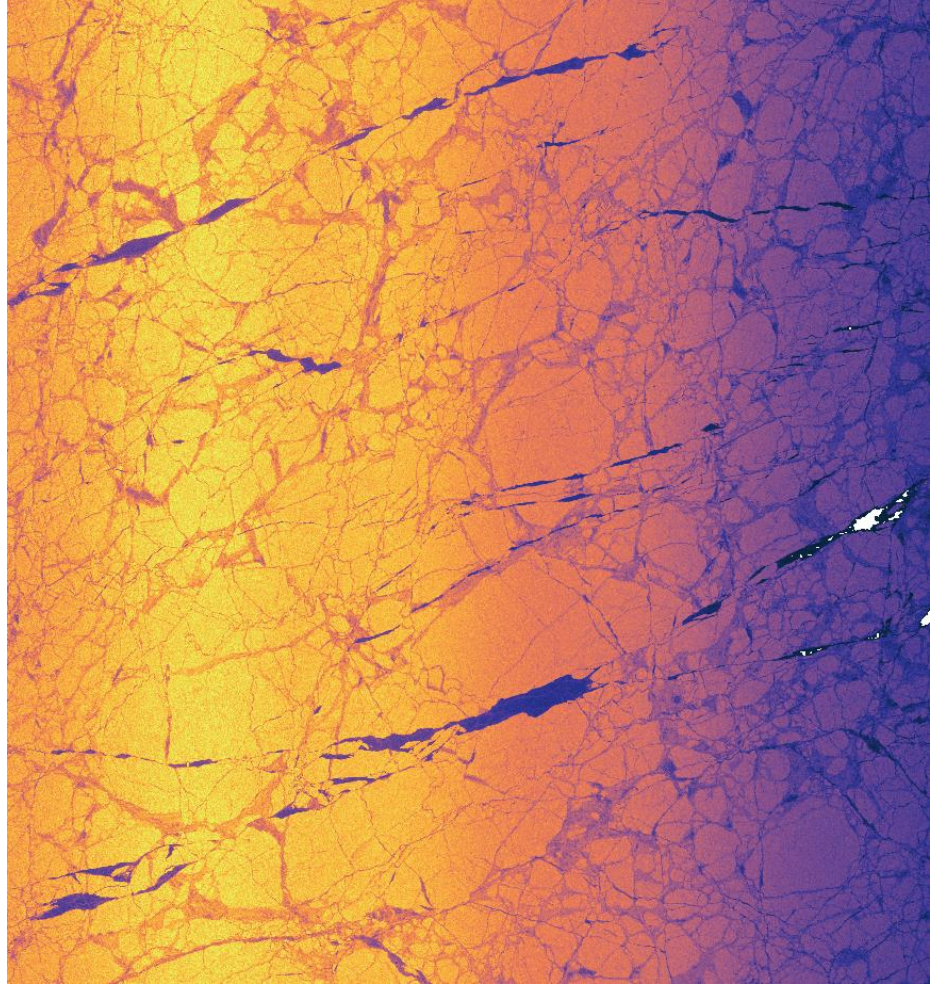
1. What are the near-nadir Ka-band backscattering properties of sea ice?
2. Given this, what is the expected performance over ice-covered oceans?

Image: Kwok (2014), “Declassified high-resolution visible imagery for Arctic sea ice investigations: An overview”, RSE

SWOT: Sea ice backscatter

Available data:

- UAVSAR - Ka-band interferometric SAR



SWOT: Sea ice backscatter

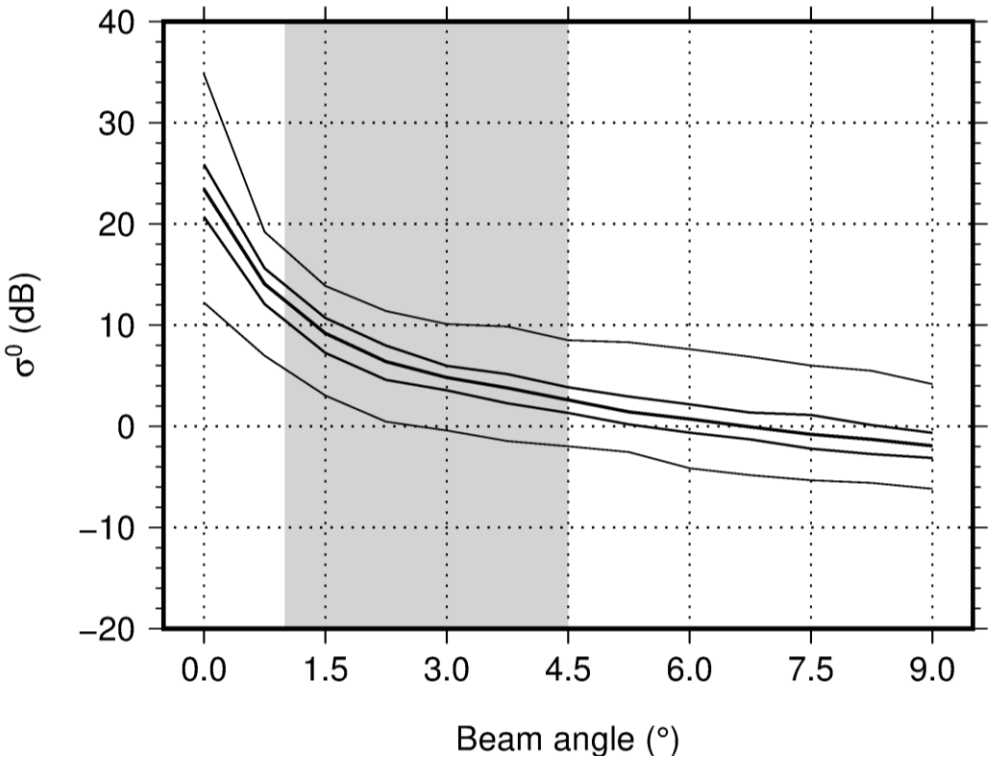
Available data:

- UAVSAR - Ka-band interferometric SAR
- Global Precipitation Measurement – Ka-band precipitation radar

SWOT: Sea ice backscatter

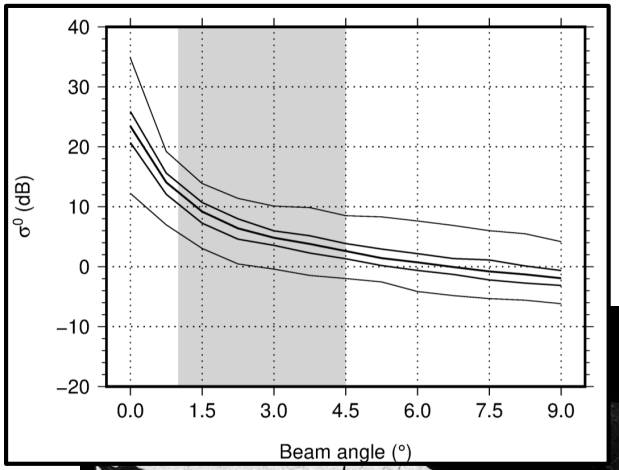
Available data:

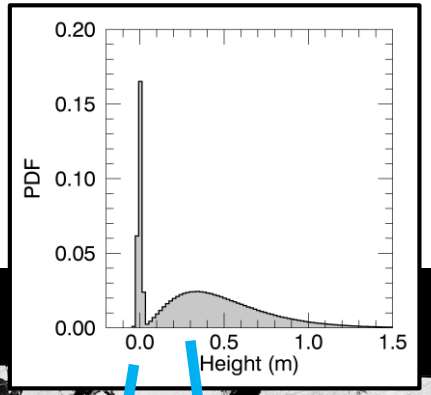
- UAVSAR - Ka-band interferometric SAR
- Global Precipitation Measurement – Ka-band precipitation radar
  - Gives Ka-band σ^0 over the range of SWOT look angles (gray)

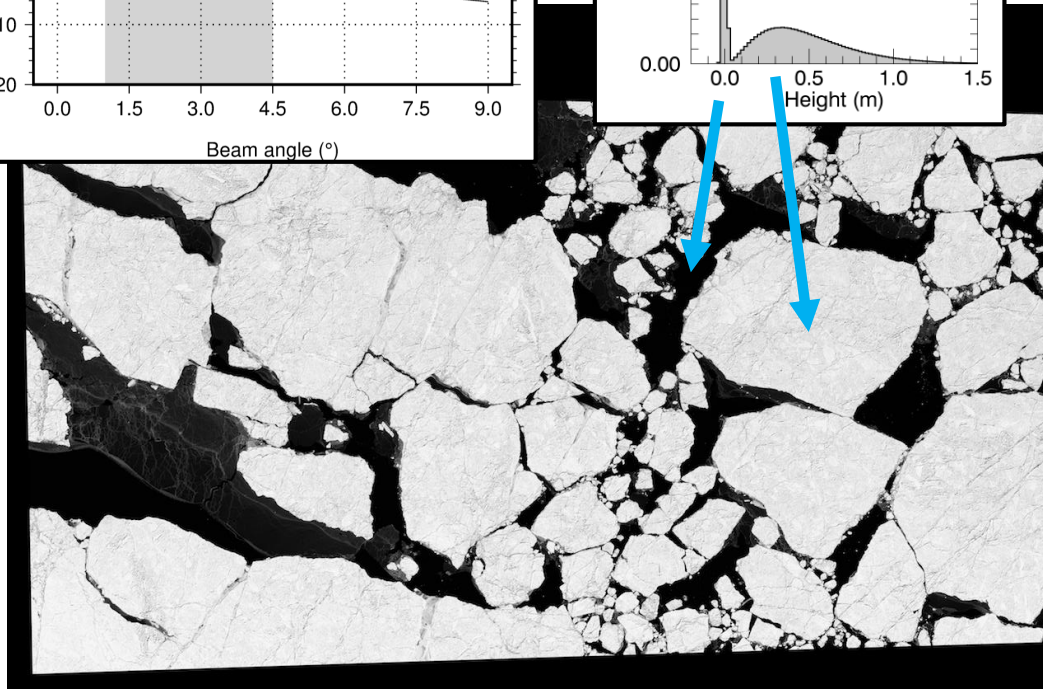


SWOT: Simulator

- Adapt the SWOT Hydrology Simulator
  - Backscatter from leads similar to inland water(?)
- Requires:
  - An input DEM
  - Surface type mask
  - Backscatter profiles

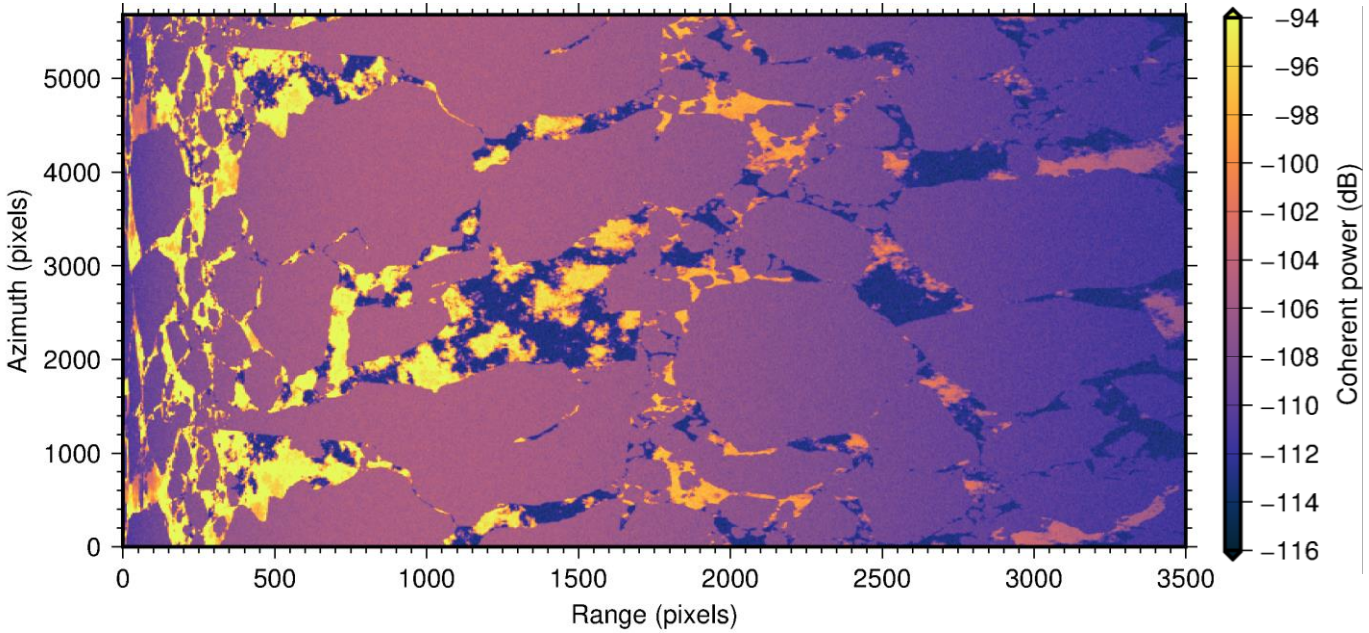






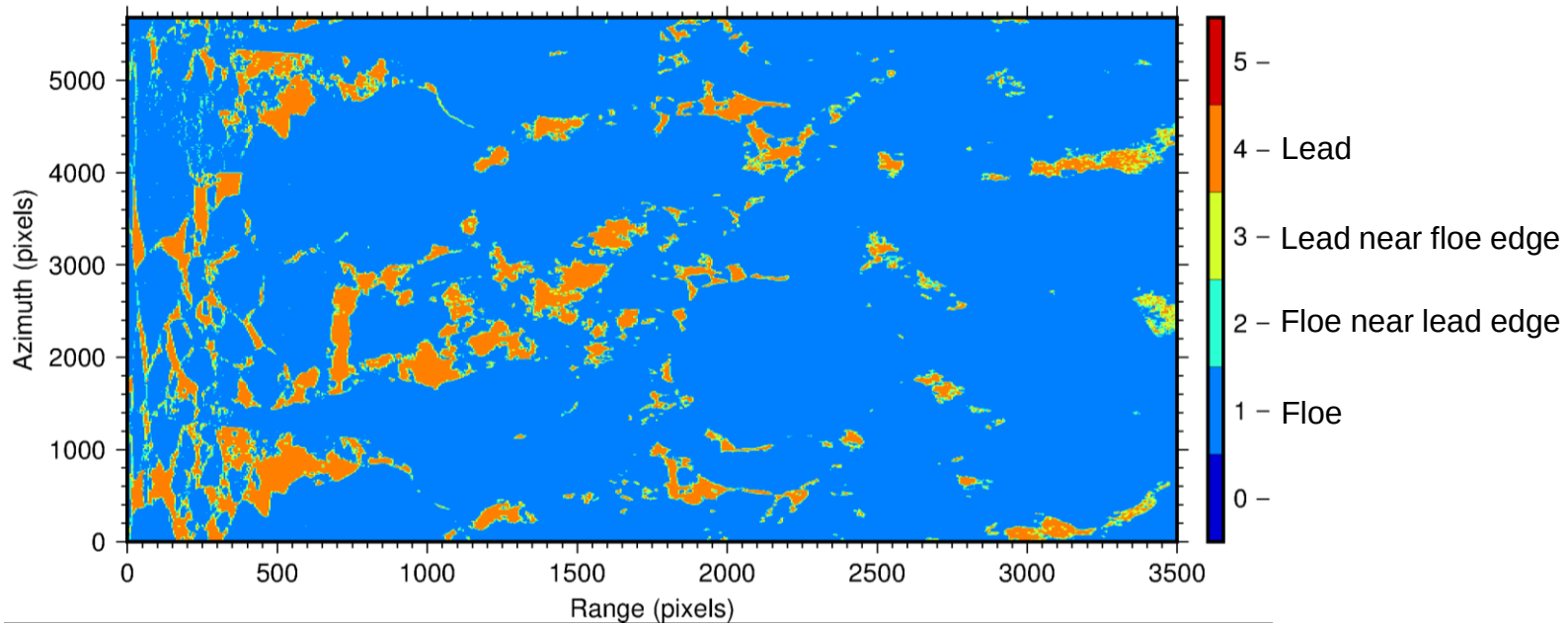
SWOT: Simulator results

Coherent power: bright area = open water; darker = sea ice



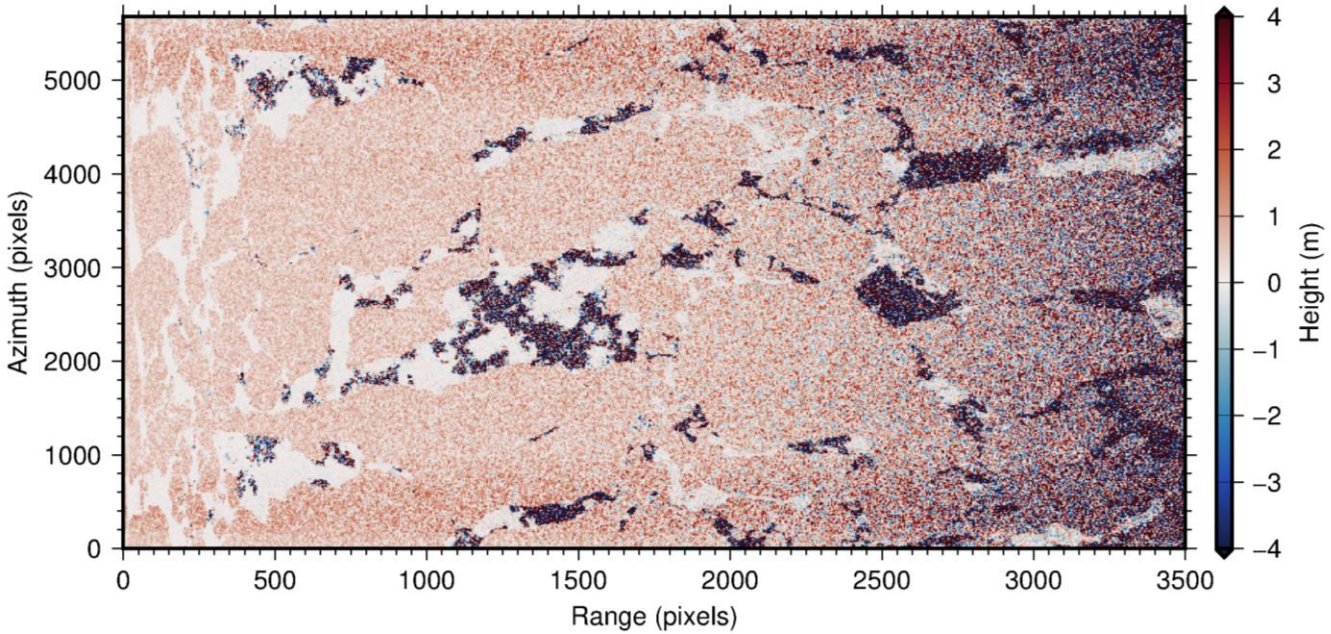
SWOT: Simulator results

Surface classification



SWOT: Simulator results

Height retrieval

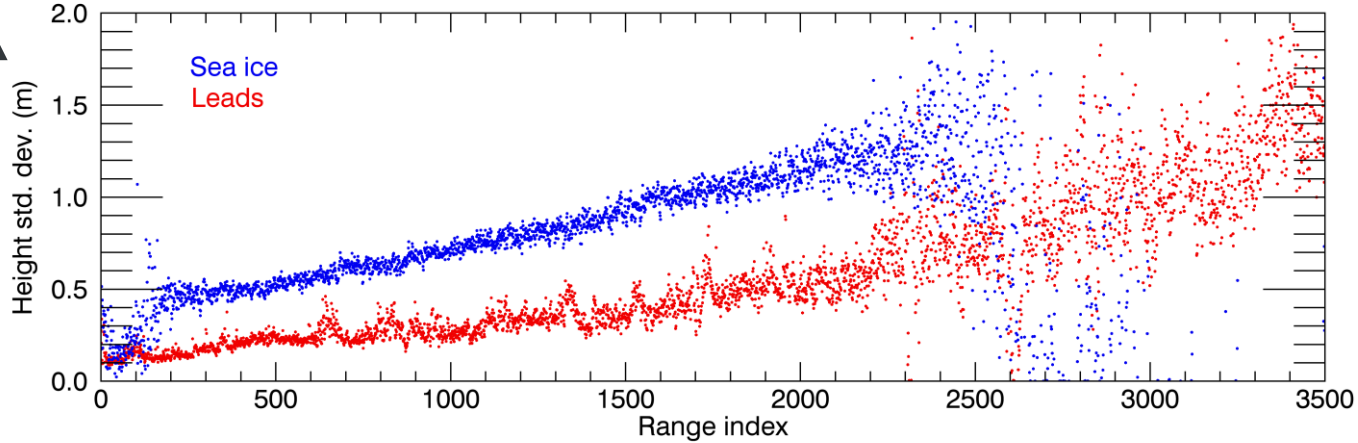


SWOT: Simulator results

Height retrieval

‘Medium’ multi-looking: 16 looks in azimuth, 3 looks in range

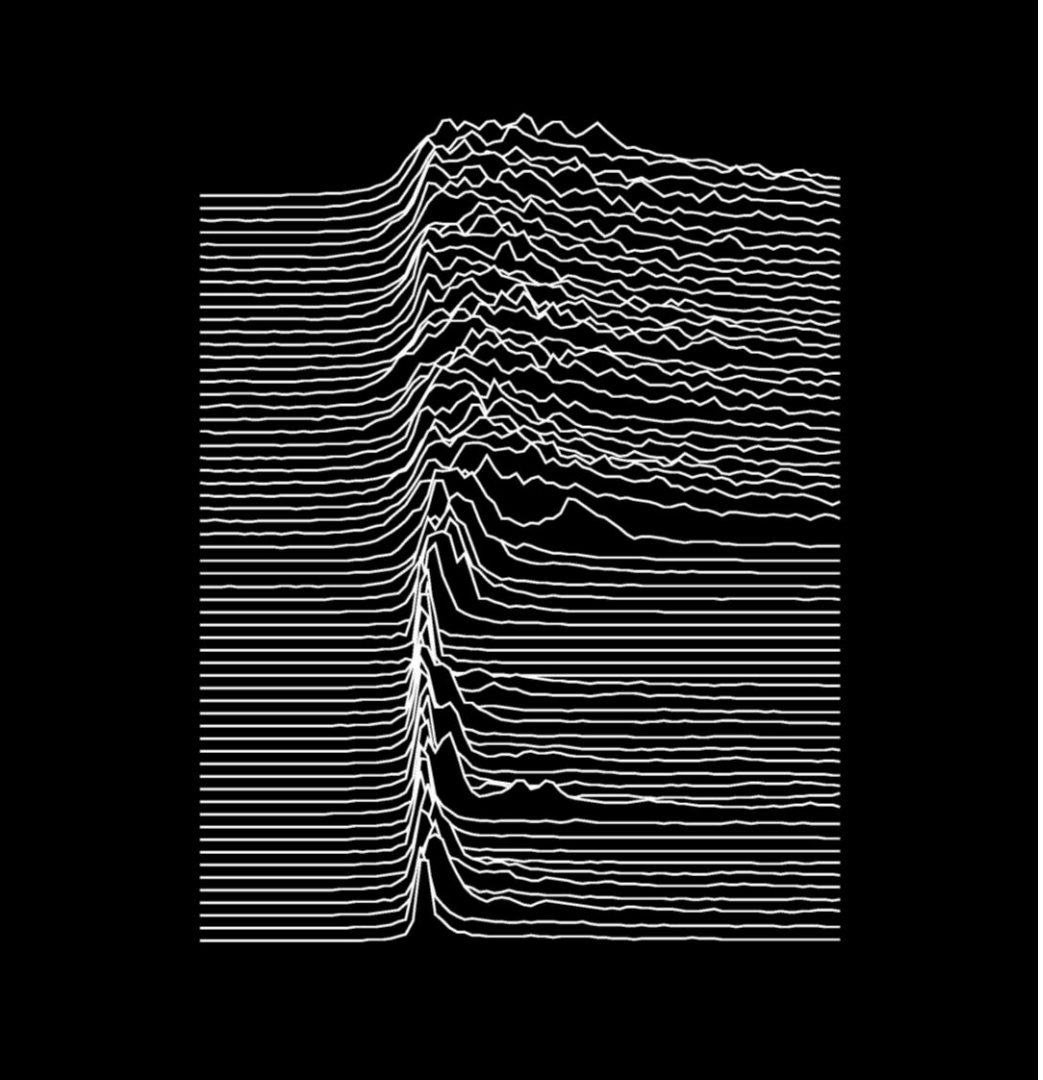
Greater height variance for sea ice than leads due to lower σ^0



Height variance increases with range as σ^0 drops off

SWOT: Future work

- What are the likely observational limits for SWOT over sea ice?
  - Refine Ka-band backscatter estimates
  - Perform simulations over range of possible backscatter scenarios
- Sea ice feasibility acquisitions currently planned for Arctic Ocean



Thanks for listening!

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